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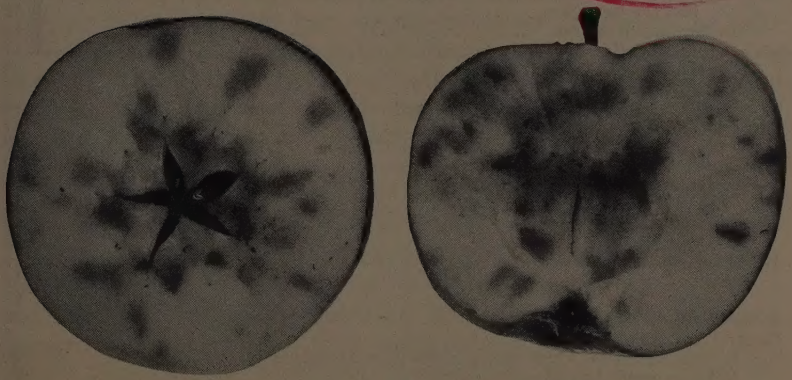
The Boron-Deficiency Disease of Apple

A. B. Burrell



INTERNAL CORK, DEVELOPED IN LATE SUMMER
(Slightly Reduced)

This is the most common of the boron-deficiency symptoms in apple. The variety shown is Cortland at harvest time

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THE BORON-DEFICIENCY DISEASE OF APPLE

A. B. Burrell

The boron-deficiency disease of apple is not new to New York State. At intervals for the past seventy-five years, growers in the Lake Champlain Valley have suffered fruit losses, though the cause has remained obscure until the past five years. Recently, the disease has given concern in all of the major fruit-producing regions of the State. The crops of individual orchards have been reduced in value by as much as 50 to 90 per cent. Although some outbreaks seem partially explainable on the basis of shallow rooting or unfortunate soil characteristics, others have been on soils that permit deep-rooting and support vigorous, high-yielding orchards.

For several decades, attention was focused largely on diseases produced by fungi and bacteria. During recent years, there appears to have been an increase in plant diseases caused by deficiencies of mineral elements. Losses have been sustained from boron deficiency in this State in such diverse crops as apples, cauliflower, turnips, beets, celery, and alfalfa.

Two farm-management practices appear to have contributed to this general situation: (1) The supply of minor elements has been reduced by excessive cultivation, and (2) concentrated, relatively pure chemical fertilizers have been substituted for part of the manure and impure chemicals formerly used.

Certain other facts help to explain the increased losses from the boron-deficiency disease of apple. There has been a spectacular rise in the number of trees of McIntosh and Cortland, varieties notably subject to this disease. Also, there has been an increasing tendency to force rapid growth by applications of nitrogen. This rapid growth increases the demand for all elements. Consequently, some soils that supplied enough boron for slow-growing trees, do not supply enough for those that are growing rapidly.

Fortunately, an economical means of controlling the boron-deficiency disease of apple has been found. The purpose of this bulletin is to enable the fruit grower to recognize and control the disease. The bulletin is based on a study which has been in continuous operation since 1925.

The major symptoms and the environmental conditions under which they occur, were illustrated and discussed by A. J. Mix[1] in Bulletin 426 of

Author's acknowledgment. The author is indebted to Dr. H. E. Thomas, of the Department of Plant Pathology, and to Dr. A. J. Heinicke, of the Department of Pomology, for guidance during the earlier years of this study.

[1]Mix, A. J. Cork, drouth spot and related diseases of the apple. New York (Geneva) Agr. Exp. Sta. Bul. 426. 1916.

the New York State (Geneva) Agricultural Experiment Station. In that publication, Mix states, "Since these diseases [cork, drouth spot, drouth dieback, and drouth rosette] may appear, to a limited extent, in a rainy season, lack of soil moisture cannot be considered their sole cause. It is, however, the one predisposing factor. Other factors, yet unknown, may be operative." Studies at Cornell between 1925 and 1930 showed that cork, drouth spot, dieback, and rosette are symptoms of the same disease rather than of separate diseases.

Nearly all references to this disease from the publication of Mix's bulletin until 1935, ascribed it to water deficiency. From that date forward, reports from such widely scattered regions as New Zealand, Canada, New York, Australia, Finland, and elsewhere, show excellent control from boron treatments, irrespective of the water supply.

The question naturally arises whether boron functions as an indispensable nutrient or merely acts through some indirect effect on the soil or plant. The final answer to this question is not yet at hand. However, the available evidence strongly favors the existence of a true nutrient deficiency.

NAMES

THE FOLLOWING terms all have been used for the fruit symptoms: *cork*, *corky apples*, *internal cork*, *corky pit*, *punk*, *punky apples*, *woody apples*, *internal browning*, *brown core*, *corky core*, *drouth spot*, *corky drouth spot*, *crinkle*, *Stevens disease*, and, mistakenly, *stippen*, *bitter pit*, *frost injury*, and *spray injury*. The term *cork* usually has been used for brown areas in the flesh, and *drouth spot* for external lesions. This is by no means universal, however, and these usages have misleading implications.

It is hereby proposed that henceforth the term *internal cork* be used for all lesions within the flesh, and *external cork* for all lesions killing the epidermis. The other names may well be dropped.

The terms *dieback* and *rosette* usually have been used for the principal twig and leaf symptoms. They are descriptive and there seems no adequate justification for changing them. To be more specific, one could say *boron-deficiency dieback*, and *boron-deficiency rosette*. The term *rosette* is used for other fruit diseases such as the virus disease, peach rosette, and for the zinc-correctable diseases known as *rosette of pecans*, and *rosette* or *little-leaf of fruit trees*. Since no suitable name was in general use, the term *incipient dieback* was proposed a few years ago[2] for the late-summer foliage and inner bark symptoms preceding actual death of twigs. The meaning of all of these terms is amplified in the discussion of symptoms.

[2]Boron treatment for a physiogenic apple disease. By A. B. Burrell. Amer. Soc. Hort. Sci. Proc. 34 (1936) :199. 1937.

SYMPTOMS

THE MANIFESTATIONS of boron-deficiency disease of apple are extremely diverse. Fruits, twigs, and leaves all are affected. The symptom-complex varies radically in different varieties. Even in a given organ of a particular variety, the symptoms differ according to the stage of development at which they appear, the intensity of the deficiency, and the vigor of the tree. Atmospheric temperature and humidity also may play a part.

In fruit

Fruits suffering from boron deficiency usually ripen a week or two ahead of normal fruits. They tend to be dry and lack acidity. When cut, their flesh turns brown more rapidly than that of normal fruits. When symptoms are initiated while the fruits are small, the seeds are abortive or poorly developed. The fruits on certain branches are much more severely affected than are those on other branches of the same tree.

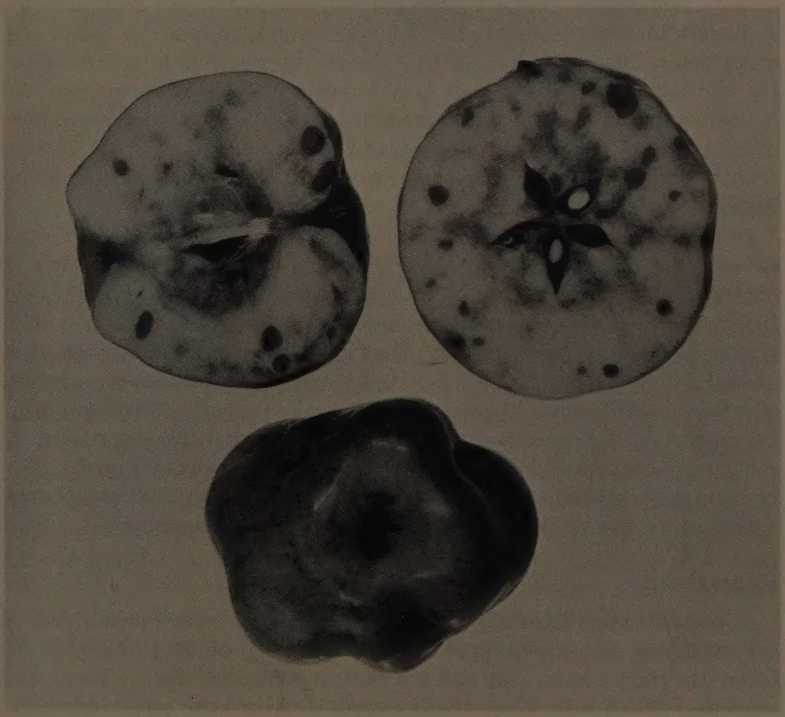

FIGURE 1. INTERNAL CORK AT HARVEST TIME—VARIETY FAMEUSE (SNOW)
Note the early-season form (rounded, hard, dry, brown spots with definite margins) and the late-season form (large, soft, light brown areas with indefinite margins)

The two main types of fruit symptoms are: internal and external cork. A single fruit may have either or a combination of the two.

Internal cork

In internal cork (figure 1), the dead cell-masses are within the flesh, the epidermis remaining approximately normal. The lesions may be at any point between the skin and the seed cavity. The first stage is a water-soaked appearance, but within a few days the affected tissue turns brown. Internal cork may appear within two weeks after petal fall or at any time from then until the fruit is mature. When it starts during the first half of the growing season of the fruit, it is known as the *early-season form;* when it starts later, it is called the *late-season form*. The symptoms of the two are different.

In the early-season form, the lesions are brown, roundish or irregular in shape, and from one-eighth to three-eighths inch across. The margins are definite. Sometimes there is a faint greenish hue to the live flesh immediately surrounding the lesion. The dead cell-masses become dry, hard, and corky before harvest and, if the fruit decays, they remain intact. Many of the worst-affected fruits drop in early summer. Those that mature may be from three-fourths inch in diameter up to normal size. The color is variable, many apples being deep red. If the fruits are severely affected, the surface contour becomes extremely irregular owing to the check in growth near the lesions.

In the late-season form (figure 2), the lesions typically are larger than those in the early-season form, have less sharply defined margins, and at harvest the texture remains soft and spongy rather than hard and corky. In extreme cases half or more of the flesh is brown. Usually the apples with late-season cork are not deformed. They ripen a week or ten days ahead of normal fruits, and often develop a darker red color. Large specimens are affected more frequently than are small ones. Very heavy dropping shortly before harvest is a characteristic of fruits with internal cork, especially in the variety McIntosh. Minor symptoms include an open calyx, and a pebbly fruit surface similar to the usual surface of the variety Twenty-Ounce. These minor symptoms sometimes are lacking or inconspicuous.

External cork

A second form of fruit symptom for which the term *external cork* is proposed, may appear within two weeks after petal fall and usually starts before the fruit is more than half grown. It more frequently is on the green than the colored side. While it more often is toward the calyx end of the fruit, this is not a consistent characteristic. The affected area commonly is from one-half to one inch across. Its shape varies from roundish to ex-

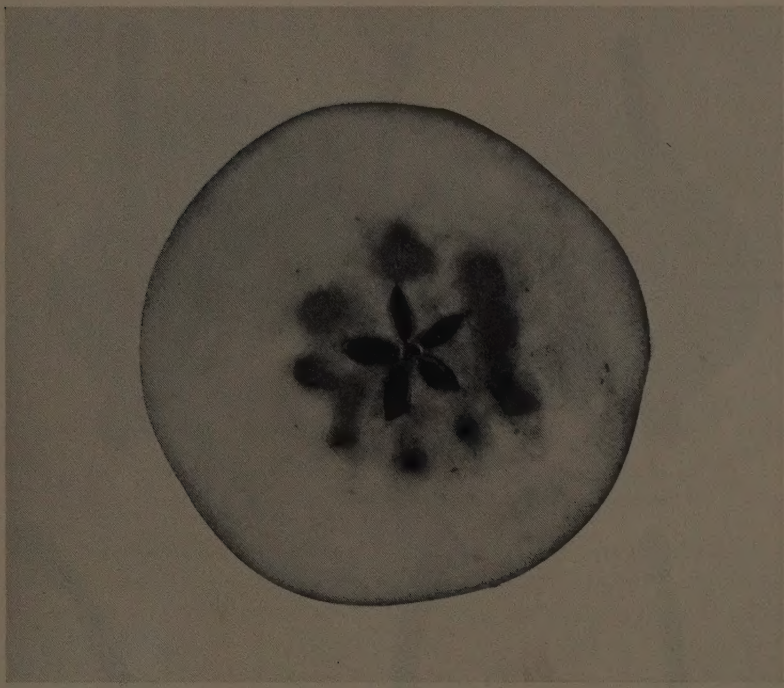

FIGURE 2. INTERNAL CORK, LATE-SEASON FORM, AT HARVEST TIME—VARIETY BALDWIN

The lesions are large and near the core. This is in contrast to stippen, which has smaller lesions chiefly near the surface

tremely irregular with rounded margins. It is first water-soaked in appearance, but almost immediately turns light brown, and becomes wrinkled and studded with droplets of clear amber-colored exudate (figure 3). This exudate hardens as it dries, but soon is weathered off. There may be several external cork areas on a single apple originating either concurrently or some days apart. Ordinarily, a lesion does not increase in the proportion to the apple surface occupied. It is as large when first visible as later, except that its area may increase as that part of the apple grows. Except in rare cases, the margin does not advance in the manner usual for lesions caused by microorganisms. In general, the external-cork lesion is superficial, though it sometimes extends to a depth of one-sixteenth inch or more. It may or may not be accompanied by internal cork.

At this stage external cork seldom would be confused with other diseases or injuries. It faintly suggests fire-blight lesions of fruit, but is readily distinguishable. Fire-blight fruit lesions cause a deep decay, and the flesh

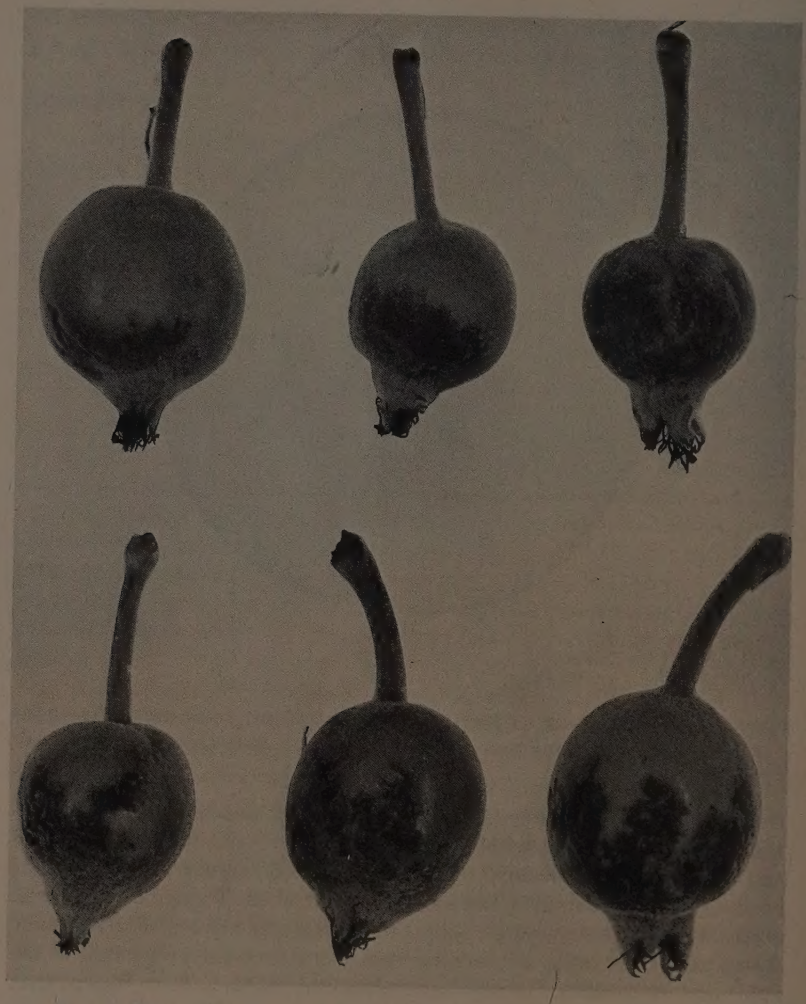

FIGURE 3. EXTERNAL CORK ABOUT THREE WEEKS AFTER PETAL FALL—VARIETY McINTOSH

(One and one-half natural size)
The lesions are several days old

is filled with a sticky ooze laden with bacteria. Unfortunately, growers rarely see external cork at this early, readily recognized, stage.

If external cork is severe, and starts when fruits are very small, most of the affected ones drop. Thus a tree may have few apples at maturity.

FIGURE 4. EXTERNAL CORK AT HARVEST TIME—VARIETY McINTOSH

Fruit diameter is about 1 inch. Note the rough cracked surface not restricted to any one portion of the fruit

Partly because of the early crop reduction, affected trees usually bloom profusely every year. Some fruits may remain attached but attain a diameter of only an inch or less at maturity. Others, but slightly affected, grow to normal size.

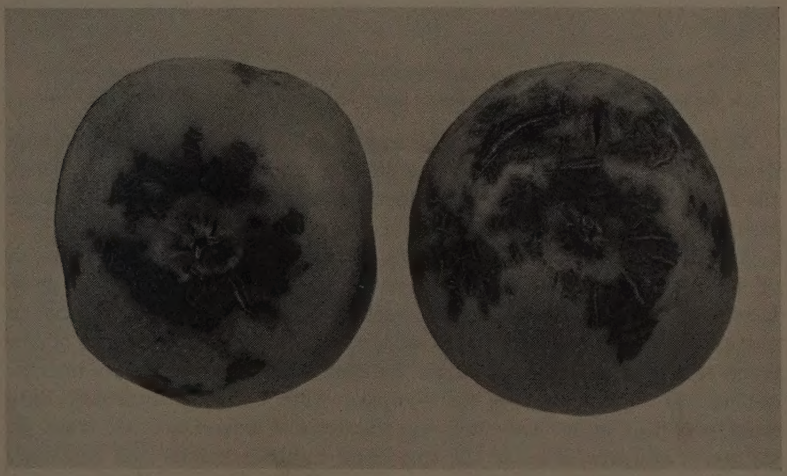

FIGURE 5. EXTERNAL CORK AT HARVEST TIME—VARIETY NORTHWESTERN GREENING

Note the healed cracks, chiefly near the calyx end

FIGURE 6.—EXTERNAL CORK AT HARVEST TIME—VARIETY NORTHERN SPY
Note the tendency toward concentric rings of russet, occasionally noted in Spy and other varieties

As with many injuries to young apple fruits, the surface of the lesion develops severe russeting. Since the affected area grows more slowly than the rest of the fruit, there may be much cracking (figures 4 and 5). These cracks may be healed with a cork-like tissue.

At harvest, the external-cork lesions frequently are confused with copper- or sulfur-spray injury, and occasionally with sunscald and heat injury. However, they are at least as frequent in the lower and interior shaded portions of the trees as on the outside, and are even more frequent on the green side of the fruit than on the red side. Their location bears no consistent relation to points of the compass, while sulfur-spray injury, sunscald, and heat injury are chiefly on the exposed side of exposed fruits on the south and west sides of the tree. External-cork lesions lack the shiny brown surface characteristic of sunscald apples. Their flesh lacks the cooked appearance, the fine brown streaks, and the deep hollows that result from heat injury.

Even more commonly the external-cork lesions are confused with frost injury. Their occurrence, however, bears no such consistent relation to elevation or topography of the land as does frost injury. The external-cork lesions tend to be roundish, while the frost injury more commonly manifests itself in bands or streaks. The external-cork lesions have irregular surfaces often covered with fine cracks, while the frost injury usually results in a more uniform russet surface. External cork often involves a browning of the outer portion of the apple flesh, while frost injury is more superficial, and lacks flesh-browning.

Contrasts between cork and stippen

So many publications have made the unwarranted assumption that cork is a form of stippen, or a closely related disease, that it seems desirable to emphasize the differences between the two.

Cork	Stippen
Is controlled by boron.	Is not controlled by boron.
May appear any time after petal fall.	Usually appears when fruit is approaching maturity.
Never is first manifest in storage.	May be first manifest either on the tree or in storage.
Does not increase during storage, though over-maturity breakdown may occur in corky fruits.	Increases during storage.
Occurs at any location on surface or within flesh.	Is most abundant near calyx end.
In some varieties, the early-season form causes large, cracked, russet areas on the surface of the fruit (McIntosh, Baldwin).	Causes no russet or cracking.
Causes severe dwarfing of fruits.	Does not dwarf fruits noticeably.
Causes severe distortion but not pitting of fruits.	Causes no distortion except pitting of fruits.
Often causes severe dropping of fruits at any time from early summer to harvest time.	Usually does not cause dropping.
Is prevalent in the varieties McIntosh, Cortland, Fameuse; less common in Baldwin, Spy, and Rhode Island Greening.	Is not prevalent in McIntosh, Cortland, or Fameuse; very common in Baldwin, Spy, and Rhode Island Greening.
Bad outbreaks usually are restricted to certain orchard areas in certain regions.	Occurs wherever apples are grown.
Is increased greatly by drouth.	Is not increased consistently by drouth.
Is not increased by rainfall shortly before harvest time.	Is increased by abundant rainfall shortly before harvest time.
Usually is not conspicuously influenced by amount of fruit on tree.	Is much more abundant on lightly-loaded than on heavily-loaded trees.
Is accompanied sometimes by rosette and dieback.	Is not known to be related to any visible foliage or twig abnormality.

What determines the type of fruit symptom

Whether an apple develops internal cork or external cork depends on the variety and the date at which symptoms are initiated. When lesions originate within the first six or eight weeks after petal fall, the variety largely determines whether the lesions will be predominantly external or internal. In McIntosh, Macoun, Baldwin, Rome, Northwestern Greening, Jonathan, and Wolf River, the lesions are predominantly external, though some internal lesions may accompany the external ones. In Fameuse (Snow), Ben Davis, Cortland, and Rhode Island Greening, lesions are predominantly internal and the epidermis remains normal. Wealthy, Oldenburg (Duchess), and Spy usually have a mixture of external and internal cork (figure 7).

FIGURE 7. EXTERNAL AND INTERNAL CORK ABOUT FIVE WEEKS AFTER PETAL-FALL —VARIETY OLDENBURG

The lesions are about two weeks old. Internal cork causes the roundish depressions in which the epidermis is normal

When several apple varieties are grafted onto a boron-deficient tree, each variety develops the type of symptom characteristic of that variety.

Regardless of variety, lesions that develop more than eight weeks or so after petal fall usually are of the late-season form of internal cork. Even the varieties McIntosh and Baldwin, in late season, develop internal rather than external cork.

Storage behavior

Apples affected by cork sometimes have been observed to break down more quickly in cold storage than do normal apples. This appears to be a breakdown of the type common in apples that are over-mature when

FIGURE 8. BARK ROUGHENING, WITH INTERNAL BARK NECROSIS—VARIETY McINTOSH

Bark roughening with internal bark necrosis such as occasionally accompanies severe dieback and rosette is a symptom of boron-deficiency disease. The vertical wrinkling of the bark is due to drying of the specimen in the laboratory rather than to boron deficiency

harvested. It does not coincide in symptoms with internal cork. It would be inaccurate to regard this as development of cork in storage. Rather, it appears to be ordinary over-maturity breakdown, explained by the fact that corky apples are at a more advanced stage of maturity than are normal apples at the usual harvest date. In the experiments at Cornell, corky apples placed in a good cold storage when hard-ripe usually kept well.

In vegetative organs

The twig and foliage symptoms are described under the names *incipient dieback*, *dieback*, and *rosette*.

Incipient dieback

Incipient dieback appears in late summer. The leaves on the terminal shoots (current year's growth) become yellowish, develop red veins, and an irregularly convex upper surface. Later the tip and parts of the leaf margin die. If the bark near the tip of the twig is peeled off, small dead brown areas are noted, especially beneath the axillary leaf buds. In time, these dead areas enlarge until most of the inner bark and the cambium are dead. The twig dies from the tip backward. Sometimes the terminal remains alive until spring, but the buds either fail to push or grow feebly, then die.

FIGURE 9. SEVERE DIEBACK IN AN EIGHTEEN-YEAR-OLD TREE—VARIETY McINTOSH

Lack of foliage makes such trees susceptible to winter injury. When large branches die, fungi soon become established in the dead bark, then invade the live bark, causing cankers which eventually kill the tree

Sometimes the application of boron or water may bring about a resumption of normal growth (figure 8) and the dead areas become buried in the inner bark. This may be the same situation as that found in the "internal bark necrosis" form of apple-tree measles.

Dieback

Dieback originates as described (figures 9 and 10). A terminal may die back into wood several years old. It is typical for several new shoots to push out from the live portion just back of the dead tip. The shoots may be either normal or of the rosette type described in the following paragraph. Often, these develop dieback; the repetition of this sequence leads to a dense, bushy type of growth sometimes referred to as "witches broom." When fresh dieback appears, it often affects the twigs that have made the strongest growth. Thus the trees with dieback become badly misshapen. Winter injury often complicates the dieback picture by killing the twigs weakened as described under incipient dieback.

Rosette

Rosette refers primarily to the occurrence of tufts of narrow leaves (figure 10). The tuft effect results from shortening of internodes. The tufts may be either at the tips of twigs otherwise bare or on spurs. The individual leaves are dwarfed, stiff, thick, brittle, and have smooth margins instead of the usual notched margins. Leaves with these characteristics sometimes develop without noticeable shortening of internodes. Rosette may develop any time during

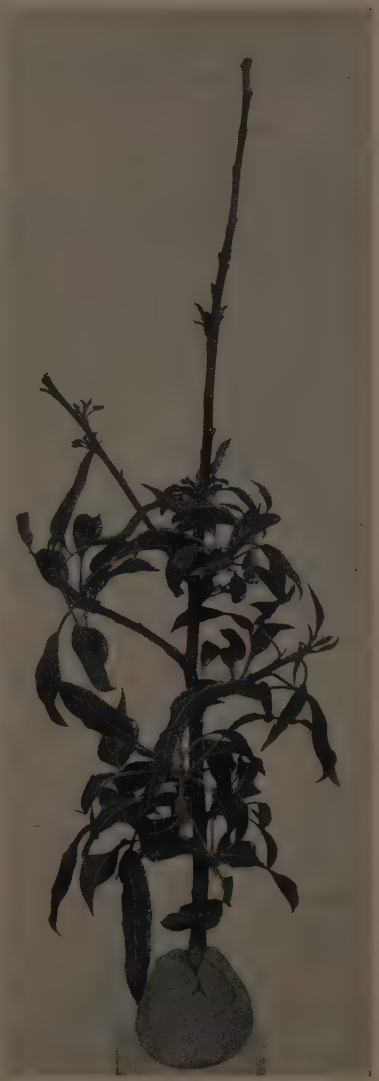

FIGURE 10. ROSETTE AND DIEBACK OF A BRANCH IN JULY—VARIETY McINTOSH
Note the narrow leaves that lack serrations

the season. At first, the leaf color is normal; but, late in the season, the rosette twigs may develop incipient dieback or dieback. On a given shoot, one sometimes sees a gradual transition from normal leaves normally spaced to narrow dwarfed leaves and short internodes. Occasionally, a reverse transition from rosette leaves to normal ones is noted (figure 11).

FIGURE 11. ONE-SEASONS TERMINAL GROWTH, AFTER RECOVERY FROM ROSETTE—VARIETY McINTOSH

Rain relieved the drouth in June and normal leaves were produced for the remainder of the year. Note that the first leaves produced were dwarfed and narrow. The few injured leaves about two-thirds of the way from base to tip are a result of potato leaf-hopper feeding and are in no way related to rosette. The photograph was taken in August

Occurrence of the different symptoms

All of the symptoms are extremely erratic in occurrence. A crop may be destroyed one year and entirely healthy fruit may be harvested the next without any change in orchard management. The twig and foliage symptoms are equally prone to come and go.

It is characteristic for certain branches to show more fruit and foliage symptoms than other branches of the same tree. The fruit symptoms may occur without any evidence of foliage or twig abnormalities. However, if a tree develops incipient dieback or rosette, the fruits that year almost invariably have cork.

Fruit symptoms are much more widespread than are the twig and foliage symptoms, and the late-season form of internal cork is much more common than are the other fruit symptoms. In fact, in most parts of New York and New England, late-season internal cork is the only symptom with which fruit growers are at all commonly familiar. It often is on trees that appear entirely normal.

The external-cork symptom was rather common in the Champlain Valley until control measures (page 20) were put into general practice. Occasionally, it has been noted in other parts of the State. The same is true of early-season internal cork.

Twig and foliage symptoms have been rare in New York State, except in the Champlain Valley. Even here, they were prevalent only certain years in certain orchards. Since the recommended control has been adopted, dieback and rosette have almost disappeared from the Champlain Valley.

BEHAVIOR OF DIFFERENT VARIETIES

THE VARIETIES that exhibit severe fruit symptoms tend to be subject to twig and foliage symptoms. However, the following statements apply to fruit symptoms only, since observations of twig and foliage symptoms are more limited. Even the statements on tendency toward fruit symptoms cover only those varieties generally grown in New York State.

Cortland, McIntosh, Fameuse, Oldenburg, and Ben Davis, are among those most severely affected. Wealthy is in the moderately affected class. Baldwin, Spy, Jonathan, Northwestern Greening, Rhode Island Greening, Golden Delicious, and Delicious are less commonly affected. Tolman Sweet is the only variety observed to grow in the midst of severely affected trees of other varieties without showing any fruit symptoms whatever. Tolman rarely shows twig or foliage symptoms, but a few clearcut cases of dieback and rosette have been noted. These constitute the only observed instance of the development of vegetative symptoms while fruits on the same branches remained normal.

IMPORTANCE

Nature of losses

THE MOST severely affected fruits drop before maturity, especially in the variety McIntosh. Affected fruits that mature are culls. While in mild cases they can be utilized for cider, their juice content is low and the income hardly covers the handling cost. Since often there may be no external evidence of late-season internal cork, it is impossible to sort out affected fruits. Buyers have been known to forsake certain regions when there was an internal-cork outbreak because there was no practical way they could be certain of getting sound fruits. When affected fruits reach the consumer, the reaction to apples in general is unfavorable.

Trees with dieback and rosette become severely stunted. They form a hopelessly bushy, lop-sided structure. To restore such trees to manageable shape, requires severe, wasteful pruning and, of course, unless the boron deficiency is corrected, pruning does not prevent dieback and rosette on subsequent growth. Trees weakened by boron deficiency show increased susceptibility to winter injury.

Amount of losses

Information is inadequate to permit an accurate estimate of the money loss due to boron deficiency in apple. Occasionally, from 50 to 90 per cent of the apples are affected in blocks of several hundred trees. In the Champlain Valley, the loss in 1933 amounted to perhaps 20 per cent of the crop. It has been between 5 and 10 per cent several recent years. The loss ran into several thousand bushels in each of a few eastern New York orchards in 1939. Many growers lost several hundred bushels apiece. Their losses usually were in the valuable varieties McIntosh and Cortland.

INFLUENCE OF ENVIRONMENTAL FACTORS

Rainfall

IT HAS long been known that outbreaks occur chiefly during dry seasons. Most authors for years attempted to explain outbreaks solely on the basis of drouth. There were losses, however, in some regions even during rainy years, and in the West in orchards receiving a normal amount of water by irrigation.

Soil conditions

Trees with boron-deficiency symptoms tend to be in groups. This early suggested that some soil peculiarity might be the casual factor, either directly or indirectly. Among the soil characteristics that have been blamed are excessive porosity causing drouth, excessive compactness, presence of either hardpan or continuously hard subsoil, irregular contour, poor drainage, low organic matter, high organic matter, excessive nitrogen, insufficient potash and phosphorus, and excessive lime in either surface or subsoil.

Instances often have been noted in which soil with one or more of these features supported trees more severely affected than their neighbors. If one were to study the situation in but a single region and for only one or a few years, he might convince himself that avoiding one of these soil conditions would be all that would be needed to prevent the disease. For example, about fourteen years ago, the trees in wet spots at Peru, New York, were the ones most conspicuously affected. Yet a few years later, in some of the same blocks, the trees in wet locations were less affected than those in the drier places.

It has been reported from the Province of Quebec, Canada, that losses are restricted very largely, to sites with alkaline, high-lime subsoils. However, in New York and New England, there are severe outbreaks sometimes on soils that are acid to a considerable depth.

In the Hudson River Valley in 1936 and 1939, some of the worst losses were on shallow soils underlain with shale. On the deeper soils, more retentive of moisture, less trouble was experienced. A contrasting situation was reported from the Shenandoah-Potomac Valley region. It is stated, there was almost no cork on some shallow, shaley soils that were shown experimentally to be deficient in water. On the other hand, the loss was severe in some orchards on deeper, more fertile, and more retentive soils.

These apparent inconsistencies are not so vexing if one regards boron deficiency as the cause, and the moisture supply, lime-content, and soil depth as merely influencing boron availability. In a dry year, moisture deficiency could interfere with boron absorption or transport. In a wet year, the wet spots could contain so little oxygen that roots would become inefficient in absorbing nutrients, including boron. That a deficiency in soil moisture sometimes is actually a vital contributing factor is shown by irrigation experiments. The application of water to the soil gave a considerable degree of control in Champlain Valley experiments in 1933 and 1934. That an abundance of lime sometimes aggravates boron deficiency in other crops either through chemical combination or increasing the population of micro-organisms, has been shown repeatedly. Many of the frequently recurring losses in apple have been in neutral or alkaline soils.

From the examples cited, however, it is apparent that there are no universal correlations between these obvious soil characteristics and liability to cork losses. The soil to choose for orchard use would be one conducive to deep-rooting, moderately retentive of moisture, and at least moderately fertile. Then, if boron deficiency does occur, it may be corrected as suggested on pages 20 to 25.

INFLUENCE OF TREE CONDITION

Vigor

TREES so deficient in boron as to have incipient dieback and rosette usually appear to be in poor vigor, especially in August and September. This has lead some to believe that the orthodox measures for invigorating trees, such as cultivation, nitrogen applications, and pruning, might overcome the trouble. Often the reverse is true. Even on low-boron soils, slow-growing trees in sod orchards not receiving nitrogen seldom are affected. Apparently, where growth is slow, the demand for boron is slight and within the boron-supplying power of the soil. When cultivation or nitrogen treatments increase the growth, they increase boron-deficiency symptoms through increasing the demand for boron. Whether there is a more specific influence of high nitrogen is an unsettled question.

Injuries

Occasionally instances are noted in which some type of injury such as winter root- or crown-killing, mouse-girdling, or experimental branch-girdling have caused symptoms of boron deficiency to appear or to increase. There are instances in which root-breakage from a 1938 hurricane in eastern New York appears to have been an aggravating factor, though in others, no such effect is evident. So many outbreaks have occurred in uninjured trees, that injuries cannot be regarded as essential causal factors.

INFLUENCE OF CULTURAL PRACTICES

As previously outlined, cultivation and nitrogen applications indirectly aggravate boron deficiency. Both hay mulch and manure mulch, continued for several years, sometimes have made boron-deficiency symptoms less prevalent. In tests made by the author, the first-year effects have been variable. Sometimes symptoms have been increased the first year of a heavy manure treatment, doubtless because of the invigorating effect of the nitrogen contained. Usually, there has been no control of the disease the first year a hay mulch was applied. Heavy and consistent mulching with hay over a period of years sometimes has caused a marked reduction in symptoms, even when additional nitrogen was applied. The control so obtained usually has been far from complete, however. In the Champlain Valley tests, pruning has not had a decisive influence in either direction.

CONTROL

Investigations on which recommendations are based

Boron treatments were included in 1926, and from time to time thereafter, in Champlain Valley experiments. However, no symptoms of boron deficiency were evident in the appropriate plots until 1936. That year, their effectiveness was beyond question.

In order to give the boron treatments a more comprehensive test, additional experiments were inaugurated in 1937, in the Champlain Valley, the Hudson Valley, and the Lake Ontario fruit belt. Orchards severely affected in 1936 were chosen for this work. Each year symptoms of boron deficiency appeared in the untreated trees in some of the experimental orchards. In 1939 they appeared in most of the experimental blocks in the Hudson and Champlain Valleys and in one in western New York. From the beginning, careful consideration has been given to both the control of the disease and the possible injury from the treatments.

In addition to the soil applications, Champlain Valley tests have included injection of boron into several hundred trees, and the inclusion of boron in sprays. Results of experiments in other places have been checked against the New York results.

Is boron needed in all orchards?

In the experiments in New York no benefits from boron applications have been observed except the prevention of the described symptoms of boron deficiency. In the State of Washington, the application of boron is said to have resulted in the production of Delicious apples of normal color and shape when the untreated trees produced apples lacking color and the characteristic five protuberances at the calyx end. Similar responses also were observed in Winesap apples. It is possible that future study in New York may show some benefit from boron treatments even where cork, dieback, and rosette have not occurred. For the present, however, it is recommended that boron be applied only by those growers who have observed one of the symptoms in the orchards. It would be good insurance to apply borax throughout a block or orchard that has shown symptoms. When only affected trees are treated, others often show symptoms in later years.

Methods of applying boron

Soil application of borax has given outstanding control of all fruit and foliage symptoms, in all parts of the State, under all weather conditions, and under all soil conditions in which tests were conducted. In the Champlain Valley, where about 75,000 trees have been treated, satisfactory results have been obtained in commercial practice as well as in experimental plots. Even after boron-deficiency symptoms had appeared in the fruits, a mid-season borax application to the soil checked subsequent development such as continued in the untreated trees.

Injection of boric acid has given control but has caused injury around the injection hole. On some trees this has been of a serious nature.

Spray treatments have given inconclusive results in Champlain Valley tests. It cannot yet be stated that the spray method will give dependable control under New York State conditions. At some concentrations and in some combinations with regular orchard sprays, borax seems to cause foliage injury, although the inclusion of hydrated lime checks this tendency.

In view of the consistently favorable results from soil applications and the limitations of the injection and spray methods, it seems best for the present that the fruit grower employ only the soil-application method. Boron sprays ultimately may prove useful in situations of mild deficiency, such as might occur two years after a soil application, or in parts of an orchard where only a trace of cork has been seen.

Which boron compounds to use

Experiments have been restricted to the two cheapest and most readily available boron compounds. These are common borax ($Na_2B_4O_7 . 10 H_2O$),

containing 11.34 per cent of boron, and boric acid ($H_3 BO_3$), containing 17.49 per cent of boron. Used at rates supplying equal quantities of boron, they have been equally effective. Commercial treatments have been with the fertilizer grade of borax since it is cheapest per unit of boron. The fine granular form is preferred because it is the cheapest, is easily spread, and does not form hard lumps as readily as does the powder form.

In British Columbia boric acid is recommended to prevent building up the already high sodium content of the soil. The small amount of borax used would have no significant effect of this sort in the humid climate of New York State.

Amount per tree

Applications that have been satisfactory in tests under a wide range of soil and weather conditions in New York are shown in table 1. Very young trees seldom show symptoms under orchard conditions, and with them the risk of injury might be excessive. If boric acid is used, the amount should be about two-thirds as much as shown for borax. Probably the amount could be reduced by one-third after the first application.

TABLE 1. RATES FOR FIRST APPLICATION OF BORAX TO TREES OF DIFFERENT SIZES*

Length of time tree has been in orchard	Approximate trunk diameter 1 foot above ground	Amount of borax for ring application on soil
Years	*Inches*	*Ounces*
0 to 3	½ to 2½	None
4 to 6	3½	2
7 to 9	5	4
10 to 12	7	6
13 to 15	10	8
16 to 24	14	8 to 12
25 and more	15 and more	12 to 16

*The size of a tree is more dependable than the age for determining the amount of borax needed.

How to apply borax

The British Columbia recommendation is to broadcast the material over the entire orchard area. This is partly because there boron benefits the alfalfa, which is a common cover crop. Evidently it benefits alfalfa in a few New York fields, but this has not been shown to be general, and some plants used as orchard intercrops are sensitive to boron injury.

In most of the experiments in New York, and in the commercial treatments in the Champlain Valley, the borax has been broadcast by hand in a ring under the tips of the branches. This has given satisfactory results, hence is suggested as the method to follow. It is essential to spread the borax evenly all around the tree. Otherwise some branches may not be supplied, and local foliage injury sometimes has resulted when the borax

was carelessly distributed in small heaps. It is convenient for the operator to use a small cup or can as a measure, and to distribute the borax by shaking the can as he walks around the tree. It is not necessary to dig or harrow the borax into the soil.

Since the amount to a tree is so small, some orchardists have considered diluting the borax with another material. Experience has shown, however, that this is unnecessary and probably introduces more problems than it solves. It is difficult to get an even mixture of two materials, especially when they differ in particle size and in specific gravity. Even if they are evenly mixed, they are likely to become partially separated during handling. This would result in getting too much borax on some trees and too little on others. Some diluents, such as lime, might measurably decrease availability of boron. A little experience enables a careful workman to get an even distribution of fine granular borax without dilution.

When to apply borax

In most of the Cornell experiments, the borax was applied three or four weeks before bloom. This seems to be an entirely satisfactory and convenient time. However, applications at various other dates also gave satisfactory results, provided there was rain to wash the material into the ground a few weeks before the appearance of symptoms. Application in late fall or winter might be undesirable because of possible washing away of dissolved borax when the ground is frozen or the tree roots are inactive.

Cost of treatment

The delivered price of fine granular borax in New York is approximately $3.50 per 100 pounds. In table 1, it is suggested that a tree with a trunk diameter of 10 inches, be given 8 ounces. The cost of material for this application then would be slightly less than 2 cents. Since it would be effective for two or three years, the annual cost for this sized tree would be less than 1 cent. For the largest trees, the cost would be less than 4 cents an application, or 2 cents a year. The cost of applying borax usually is a fraction of a cent a tree.

Fertilizers containing boron

Certain fertilizer materials and mixed fertilizers are advertised to contain minor elements. Seldom, however, does the label or description tell which minor elements are present, in what amounts, in what forms, or in how available a condition.

It is conceivable that the consistent use of a material or mixture containing a very small amount of boron for a period of years might relieve or even control boron deficiency in apple. This has not been proved, how-

ever. Strong leaching could prevent the building up of the boron content of the soil by this procedure. Strong fixation by soil or by other fertilizer constituents could prevent adequate absorption by the tree when only very small amounts are included. With nitrogen carriers, increased growth from the nitrogen seems to increase the boron requirement of the tree by an amount greater than is supplied by the carriers.

The possible significance of the boron in Chilean nitrate of soda in connection with boron deficiency in apple is being studied. The field data as yet are inadequate to give the complete picture. However, in a limited number of tests, the amount of internal cork has been about the same with Chilean nitrate as with other nitrogen carriers. It has been greater on trees invigorated by Chilean nitrate than on similar trees making poor growth as a result of nitrogen deficiency. It has been shown that the boron content of Chilean nitrate is variable.

Since there is no certainty of control from such boron-containing fertilizers as are generally available and since application of borax is convenient and cheap, it is recommended that dependence be placed on borax rather than on boron-containing fertilizers.

How often must borax be applied?

In numerous tests one application of borax to the soil has been effective for two years. In the few New York tests that have run that long, one application has been effective for three years. A few corroborative observations in British Columbia and elsewhere indicate that three years may be the maximum period of protection from one application. Data from New Zealand show that three years after soil treatment, the boron content of apples had dropped to a critical level below which there might be danger of cork. Under some circumstances, leaching of boron is rather rapid.

Certain 1936 injections of boric acid into tree trunks had lost their effectiveness in 1939. This does not mean that soil applications necessarily would run out in the same period.

Until the duration of the effectiveness of a single soil application is established, it is suggested that fruit growers with a cork problem make treatments every three years. By waiting too long, one might encounter a serious loss.

Risk of injury from use of boron

With the injection method, injury is so great that the method is ruled out so far as commercial practice is concerned.

The spray method was mentioned as not having proved a dependable means of overcoming boron deficiency under New York conditions. The use of borax in the regular sprays sometimes was injurious unless they

FIGURE 12. LEAF INJURY FROM TOO MUCH BORON—VARIETY McINTOSH

Note the fading of leaf-blade color especially near principal veins, and in severe cases, the rolling of leaves, and the marginal scorching. The photograph was taken in July

contained lime. Therefore, it is recommended that even for trial use, at least 1 pound of hydrated lime be included for each pound of borax.

In soil applications, no injury has been evident from a single application of three times the recommended amounts, when the material was distributed evenly under the tips of the branches. Some injury was evident where six times the recommended amount was used. Even the recommended amount has caused a trace of leaf injury where borax was carelessly tossed into small piles instead of being distributed as suggested. About twice the recommended amount applied close to the tree trunks annually, produced leaf injury in one of eight trees the seventh year of this experiment.

One New Zealand report indicated an increase in physiogenic breakdowns and in fungous rots of apples after six months in storage at 38° F., as a result of soil applications of borax, especially where the applications were heavy. This was not corroborated by a preliminary study in the Champlain Valley. More experimentation is needed on this point. If these New Zealand results should be confirmed, possibly it might be desirable to make very light annual applications instead of following the suggestions outlined in this bulletin.

Boron-injury symptoms

One symptom of boron leaf injury is distinctive. The green color of the leaf disappears along the midrib and larger lateral veins. This is especially pronounced near the base of the leaf (figure 12). Defoliation follows severe damage. In extreme cases, shoots become spindling, while leaves curl upward and are dwarfed. These extreme injury symptoms have been observed only in purposely excessive experimental applications.

CONCLUSION

THE DIVERSE symptoms of boron deficiency of apple have been described and illustrated. A procedure for their control has been outlined. Additional experiments may result in modification of details. Of these the county agricultural agent will be kept advised.

While the evidence at hand provides a commercially useful and practical means of control, more information is needed on several aspects of the problem. The precise function of boron in the physiology of the tree is imperfectly understood. More information is needed on the influence of boron treatments on yield, on the duration of the effectiveness of a single treatment, on the cumulative effects of repeated treatments, on the boron status of soils and trees, on what happens to boron applied to the soil, on the effects of boron treatments on trees not showing deficiency symptoms, on the influence of boron treatments on storage behavior, and on the influence of boron on cover crops. Experiments now under way should throw light on some of these problems.

SUMMARY

KNOWN in New York State for three quarters of a century, the boron-deficiency disease of apple has become more serious during recent years. It may cause either internal or external lesions in the fruits, and dieback and rosette in the vegetative organs of the tree. Internal lesions developed in late summer are the commonest expression of the disease. In New York, dieback and rosette are restricted almost entirely to those few orchards in the Champlain Valley where boron deficiency is most acute.

The symptoms on fruit often are on those trees with apparently normal foliage; if the foliage is affected, the fruits almost invariably are ruined.

McIntosh, Fameuse, and Cortland are among the varieties most seriously affected. No variety is known to be totally immune, although the fruit symptoms have not been observed in Tolman Sweet.

Apples developing symptoms early in the season become dwarfed and distorted, and many of them drop within a few weeks after petal fall. Those in which symptoms appear in late summer contain brown flesh lesions, lack acidity and juiciness, and may drop prematurely. A whole crop may be depreciated because of the difficulty or impossibility of detecting those fruits with internal lesions. Sometimes 50 to 90 per cent of the crop in individual blocks is affected.

The principal outbreaks are during dry years. The effect of drouth seems to be indirect, involving a reduction in the availability of boron. Outbreaks are more frequent on shallow or excessively porous soils than on deep soils of moderate or heavy texture. Some of the orchards most frequently affected are on neutral or alkaline soils. Exceptions to these trends are numerous.

Trees whose vigor has been increased through nitrogen fertilization or soil cultivation are more seriously affected than are adjoining trees making slow growth because of nitrogen starvation. Mulching sometimes alleviates the boron-deficiency disease.

Extensive experiments show that treatments with boron compounds control the disease. Boron treatments seem beneficial in New York only in the prevention of the specific symptoms described in this bulletin. Therefore, boron is recommended only for orchards that have exhibited these symptoms.

The Cornell experiments included application of boron compounds by soil application, by spraying, and by injection. Of these methods, soil application seems best adapted to general commercial use in New York, although the spray method occasionally may prove useful under special circumstances.

Of the various boron compounds, common borax seems best adapted to commercial use because of its availability and cheapness. The fine granular form is most convenient to apply. The amount must be adjusted carefully to the size of the tree, as outlined in table 1 (page 22). It is suggested that the material be applied, undiluted, in a ring beneath the tips of the branches of each tree.

Excellent results have been obtained from borax applications three or four weeks before apple trees bloom, although this is not the only time the material may be applied.

Since borax costs from 3 to 4 cents a pound, the material cost for an application usually is from 1 to 4 cents according to the size of the tree. One treatment usually is effective for three years. The fruit grower with a cork problem should apply borax rather than depend on fertilizers advertised to contain minor elements. Most of such fertilizers contain too little boron to produce marked benefits.

The injection of boron compounds causes so much injury to the tree trunk that it is unsuitable for commercial use. The addition of borax to ordinary apple-spray mixtures brings about some imperfectly understood reactions, and under some circumstances causes foliage injury. Even application to the soil calls for rather careful measurement and distribution of the borax.

When very excessive borax applications are made, the leaf color fades along the midrib and the principal veins, producing a diagnostic symptom of boron injury.

An extensive experimental program on the effects of boron on apple trees and fruits is being continued. The results may lead to modification of some details in the control recommendations.

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